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COMMISSIONING OF THE STAR TEST SECTION FOR EXPERIMENTAL SIMULATION OF LOSS OF COOLANT ACCIDENT USING THE EC-208 INSTRUMENTED FUEL ASSEMBLY OF THE IEA-R1 REACTOR

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ABSTRACT

The three basic safety functions of Research Reactors (RR) are the safe shutdown of the reactor, the proper cooling of the decay heat of the fuel elements and the confinement of radioactive materials. Compared to Nuclear Power Reactors, RR power release is small, yet its three safety functions must be met to ensure the integrity of the reactor. During a loss of coolant accident (LOCA) in pool type RR, partial or complete loss of pool water may occur, with consequent partial or complete uncovering of the fuel assemblies. In such an accident, the decay heat removal safety function must not be compromised. The Test Section for Experimental Simulation of Loss of Coolant Accident (STAR) is in commissioning phase. This test section will provide experimental data on partial and total uncovering of the EC-208 instrumented fuel assembly (IFA) irradiated in the IEA-R1. Experimental results will be useful in validation of computer codes for RR safety analysis, particularly on heat removal efficiency aspects (safety function) in accident conditions. STAR comprises a base on which is installed the IFA, the cylindrical stainless steel hull, the compressed air system for the test section emptying and refilling, and the instrumentation for temperature and level measurements. The commissioning tests or pre-operational check, consist of several preliminary tests to verify experimental procedures, the difficulties during assembling of STAR in the pool, the difficulties in control the emptying and refilling velocities, as well as, the repeatability capacity, tests of equipments, valves and systems and tests of instrumentation and data acquisition system. Safety, accuracy and easiness of operation will be checked.

1. INTRODUCTION

One year after the Fukushima accident, Yukiya Amano, Director General of the International Atomic Energy Agency (IAEA) said that nuclear safety was stronger than it was before the accident [1]. The three basic safety functions of Research Reactors (RR) are the safe shutdown of the reactor, the proper cooling of the decay heat of the fuel elements and the confinement of radioactive materials [2,3]. Research Reactors operate in general in powers lower than the Power Reactors. Nevertheless, the fulfillment of these three safety functions is fundamental in this type of reactors.

The loss of coolant accident (LOCA) has been considered for many reactors the design basis accident (DBA) [4]. DBA are the "accident conditions against which a nuclear power plant is designed according to established design criteria, and for which the damage to the fuel and the release of radioactive material are kept within authorized limits" [2].

To proper simulation of this accident it is necessary to use qualified codes [3]. Among the qualifying steps is its validation with experimental data [3,5]. The test section for analysis of loss of coolant (STAR) (in commissioning phase) [6] proposes the simulation of LOCA with total and partial uncovering of the instrumented fuel assembly (IFA) EC208 of the IEA-R1 Reactor [7,8]. The IEA-R1 is a pool type research reactor, moderated and cooled by light water, with MTR (Material Testing Reactor) fuel assemblies, projected to a maximum power of 5 MW. The IEA-R1 is located at the IPEN-CNEN/SP (Instituto de Pesquisas Energéticas e Nucleares - Comissão Nacional de Energia Nuclear/São Paulo), in São Paulo, Brazil.

The aims of this paper are: to present the commissioning tests (section 2) that are being conducted in STAR section. Will be also presented preliminary simulation calculations using TEMPLOCA [9] and 3D-AIRLOCA programs [10] (section 3).

2. COMMISSIONING TEST OF STAR

The STAR section consists of a base, a cylindrical stainless steel hull, a compressed air system and the instrumentation.

Commissioning tests or pre-operational tests of STAR section consist of:

- ✓ assembling and installation in the reactor pool;
- ✓ test of instrumentation in the Data Acquisition System (DAS) of the IEA- R1;
- ✓ test of compressed air system, responsible for emptying and refilling of the section;
- ✓ simulation of the experiments of total and partial uncovering of the IFA. (This step has not taken place yet).

2.1. Assembling and Installation in the Reactor Pool

The installation sequence of the STAR section in the pool of the IEA-R1 is presented in Figures 1 to 3. Figure 1 shows the installation of the base into the pool, and its positioning on the platform of the thermal column. The installation of the stainless steel hull over the base is shown in Figure 2. Figure 3 shows the positioning of the IFA near to the STAR.

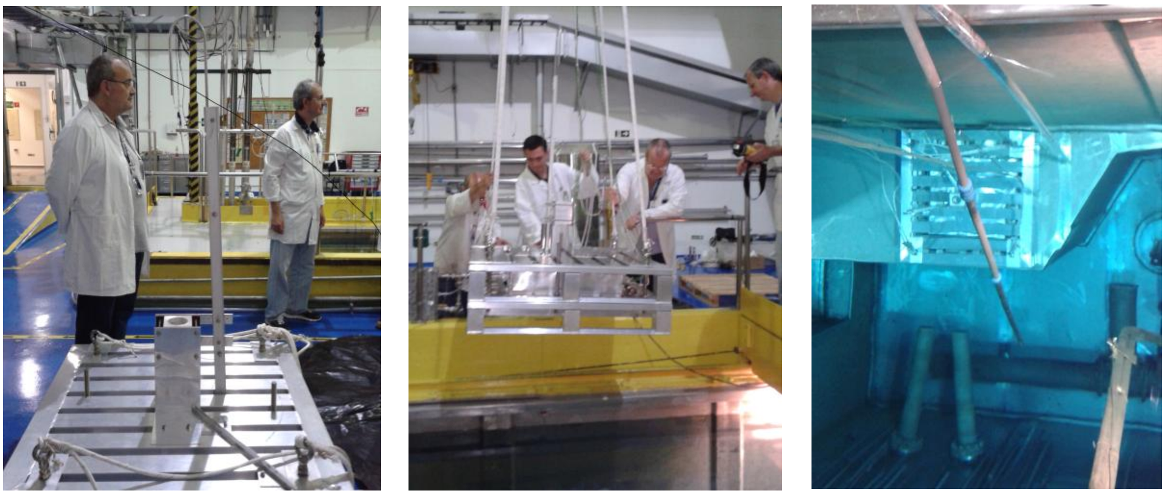

Figure 1: STAR base installation in the pool of the IEA-R1 reactor.

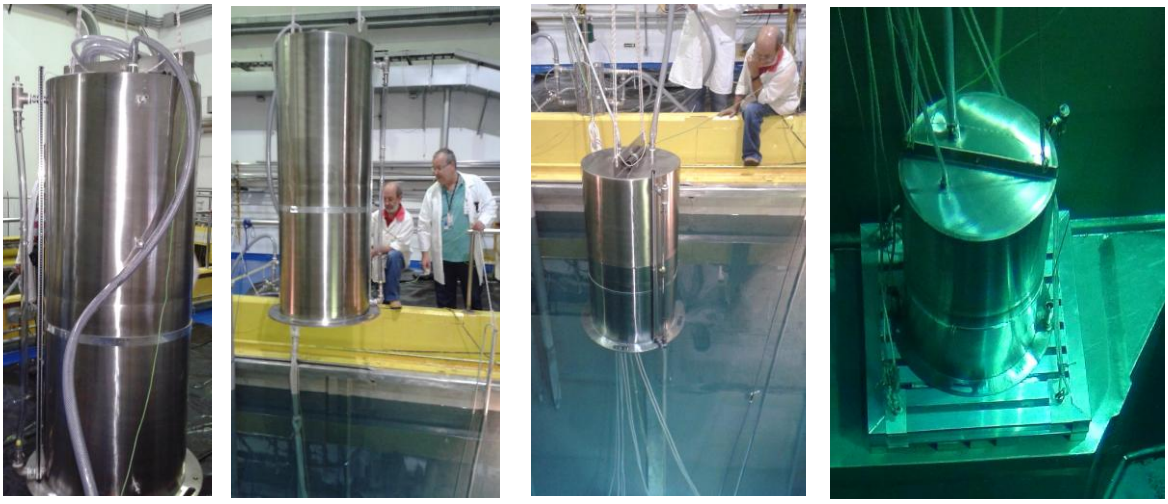

Figure 2: STAR hull installation in the pool of the IEA-R1 reactor.

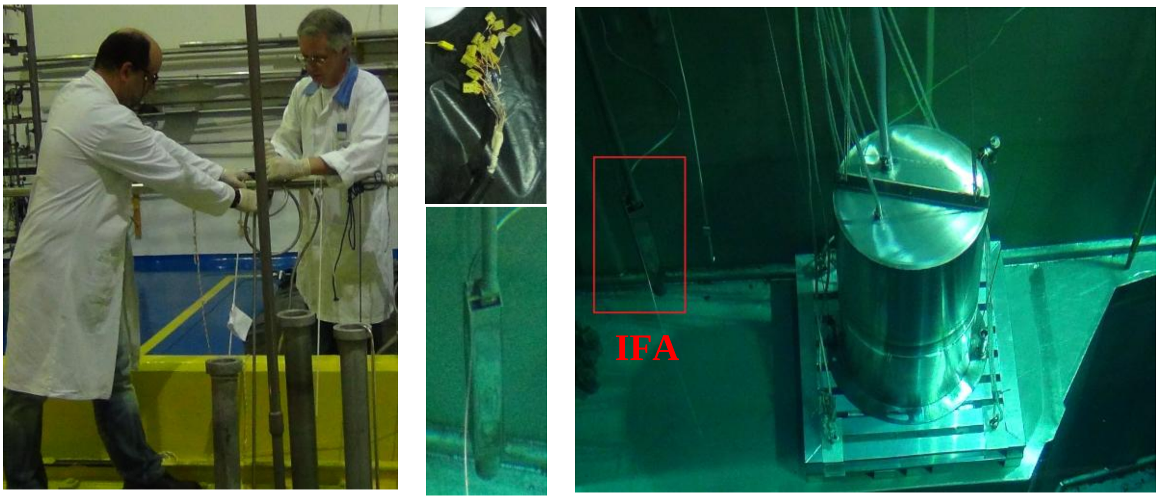

Figure 3: Positioning of the IFA near to the STAR.

2.2. Test of Instrumentation in the Data Acquisition System (DAS) of the IEA- R1

The DAS of the IEA-R1 was modified to receive 4 additional thermocouples and the water level of the STAR. The water level of the pool is also available in this revised DAS screen. In this test, it was verified the functioning of the 14 thermocouples (k type) of the IFA, and the water level measurement in the section using a differential pressure transducer (Validyne). The verification of the 4 additional thermocouple (k type) of the section is still pending. Figure 4 shows the screen for the STAR experiment in the DAS of IEA-R1. TF1, TF15, TF16, TF17 and TF18 are the indications of the 4 additional thermocouples of the STAR. TC2 to TF14 are the indications of the 14 thermocouples of the IFA. “Nível Piscina” indicates the water level of the pool and “Nível STAR” the water level of the STAR.

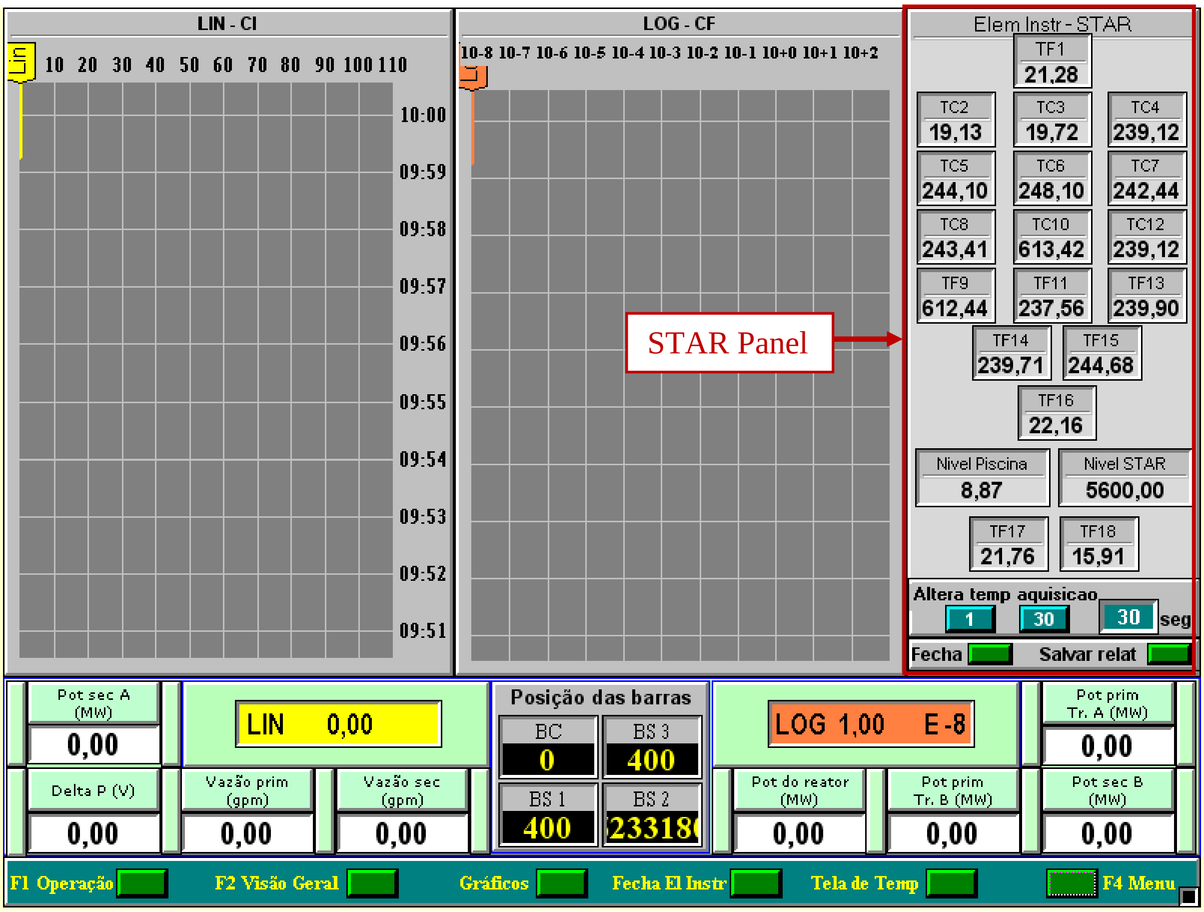

Figure 4: STAR screen of the DAS of the IEA-R1

The IFA, with its 14 thermocouples, has already proved its operating efficiency in the DAS successfully [8]. At present, the IFA is outside of the reactor core, with the thermocouples disconnected from the DAS. In this test, the IFA is fully submerged in the pool, and its 14 thermocouples were connected to the DAS successfully. Table 1 shows the IFA temperatures registered in DAS. The verification of the water level measurement system of the STAR is presented in section 2.3.

Table 1. Temperatures of IFA registered in the DAS

Time (s)	0	30	60	90	120	150	180	210	240	270	300
TC2	29.2	29.2	29.2	29.2	29.3	29.3	29.3	29.3	29.3	29.3	29.3
TC3	29.2	29.2	29.2	29.3	29.3	29.2	29.3	29.3	29.3	29.3	29.3
TC4	29.3	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4
TC5	29.4	29.4	29.3	29.4	29.4	29.4	29.5	29.4	29.4	29.5	29.5
TC6	29.7	29.8	29.9	29.9	29.8	29.8	29.9	29.9	29.9	29.8	29.8
TC7	29.9	29.9	29.9	30.0	29.9	29.9	30.0	29.9	30.0	30.0	30.0
TC8	29.6	29.6	29.6	29.7	29.7	29.6	29.7	29.7	29.7	29.7	29.6
TC9	29.0	29.0	29.3	29.0	29.3	29.3	29.3	29.0	29.0	29.0	29.0
TC10	28.8	28.8	29.0	28.8	29.0	28.8	28.8	28.8	29.0	29.0	29.0
TC11	30.2	30.2	30.2	30.2	30.2	30.3	30.2	30.2	30.2	30.2	30.3
TC12	29.6	29.6	29.6	29.7	29.6	29.7	29.6	29.7	29.6	29.6	29.7
TF13	29.7	29.7	29.7	29.8	29.7	29.7	29.7	29.8	29.7	29.8	29.7
TF14	29.2	29.2	29.2	29.3	29.2	29.2	29.2	29.3	29.2	29.2	29.2
TF15	28.7	29.0	29.0	29.2	29.3	29.0	29.3	29.2	29.4	29.4	29.4

2.3. Test of Compressed Air System

The compressed air system of STAR is responsible for emptying and refilling of water in the section. It consists of valves, hoses, tubes and connections. It receives air from the compressed air system of the IEA-R1, sends to the STAR section and return to the system of ventilation and air conditioning (VAC) of the IEA-R1.

Figure 5 shows the emptying and refilling velocities in the test section (without IFA) with results of the DAS of the IEA- R1. The results show an emptying in about 460 s (7.7 min) and a refilling in about 930 s (15.5 min).

The repeatability of emptying and refilling is achieved with the adjustment of the pressure of the compressed air system to 2.0 bar and fixing the inlet and outlet control valves in positions established.

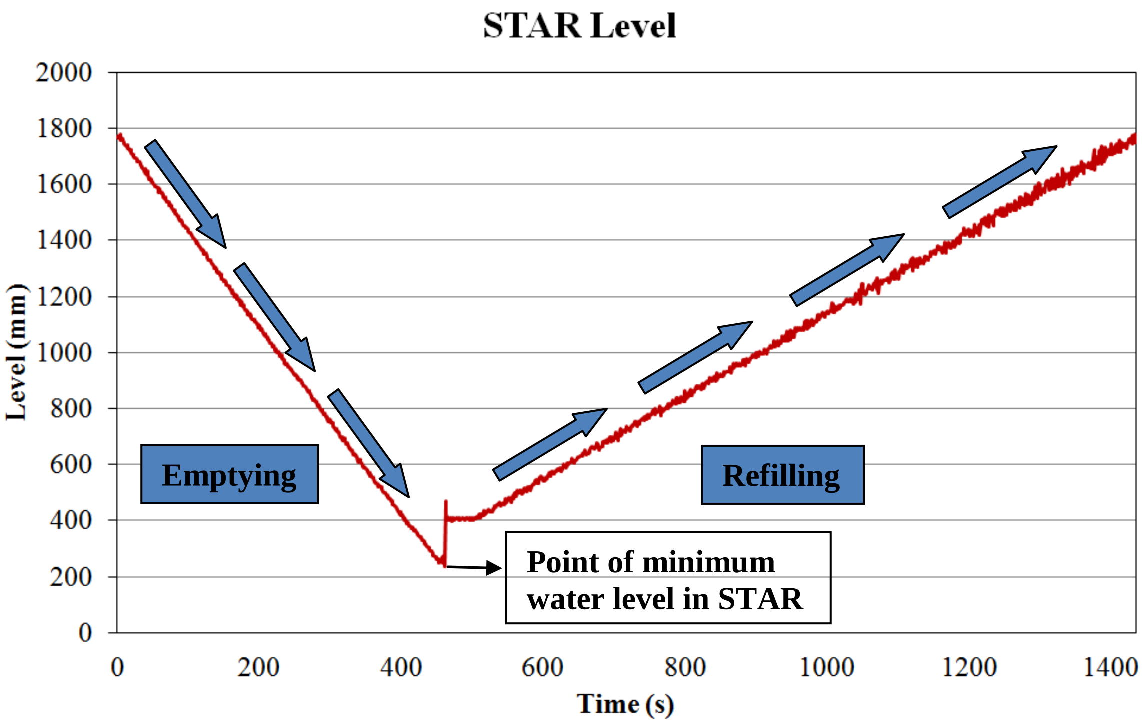

Figure 5: Emptying and refilling velocities in the STAR.

3. ESTIMATED CALCULATION OF EXPERIMENTS

This section presents the estimative calculations of the cladding temperatures during the experiments. These calculations aim the preservation of the integrity of the IFA, and also to estimate the times for the experiments. Initially, four experiments of loss of coolant are being previewed. Two for total uncovering (T-1 and T-2) and two for partial uncovering (P-1 and P-2). Calculations for T-1 and T-2 Experiments are done with the program TEMPLOCA [9], while for P-1 and P-2 experiments with the 3D-AIRLOCA code [10].

For all experiments, it was considered a reactor operating condition of 4.5 MW for 2.5 days (64 h), a radial power factor of 1.1 and a 10% overpower. The experiments will be interrupted if or when the cladding temperature (measured in the DAS) reaches 100 ^{o}C in the IFA. This value is very below of limit temperature of blistering of the fuel assembly, that is 500 ^{o}C [11] and was established to protect the IFA against thermal shock. This boundary will be called *protection limit temperature*. If the estimated cladding temperatures are conservative, we could have a longer time for the *protection limit temperature* (100 °C) to be reached (if reached). If the estimates are not conservative, we would have to interrupt the experiments in less time than calculated.

TEMPLOCA. The computer program TEMPLOCA was developed for the LOCA analysis of the IEA-R1 Reactor, when its power was increased to 5 MW [9]. It uses a correlation for calculating the maximum cladding temperature at the core as shown in [12] based on the experimental results of ORR (Oak Ridge Reactor) and in accordance with data from the LITR (Low Intensity Testing Reactor) tests [13]. This correlation applies only for fuel elements exposed to the air and without any obstructions of air circulation (total discovery). Reference

[9] presents the program and its validation with experimental data of total refrigerant loss (without obstruction).

3D-AIRLOCA [10] is a computer program developed by the Argonne National Laboratory (ANL) to model the heating of the core followed of a postulated total loss of coolant accident in nuclear pool type reactors. It can model plate-type elements with internal air flow and plate-type elements with no internal air flow. (blocked plate-type). Each element can be divided into 27 axial nodes. At the beginning of the transient, it is assumed that the core is completely dry, with a temperature profile starting supplied as input. The 3D-AIRLOCA can calculate temperatures of the fuel, air, grids, reflector elements and structural components during transients.

3.1. T-1 and T-2 Experiments

In **T-1 Experiment** (T for Total uncovering), the IFA will be totally uncovered with no obstructed air circulation for cooling the IFA. The beginning of the experiment will occur only 64 h after the reactor shutdown, to ensure a significant reduction of the decay heat and the temperatures reached in the IFA. This experiment will be used as a test to validate the procedures and calculation models. The decay heat to T-1 and T-2 experiments was calculated by the equation of Way-Wigner, which is already part of the calculation options of the program TEMPLOCA. Figure 6 presents the results of cladding temperatures in function of time to the T-1 experiment. According to this estimate at time 39 min would be reached the *protection limit temperature* of 100 ^{o}C, and the consequent interruption of the experiment with the slow refilling of the section.

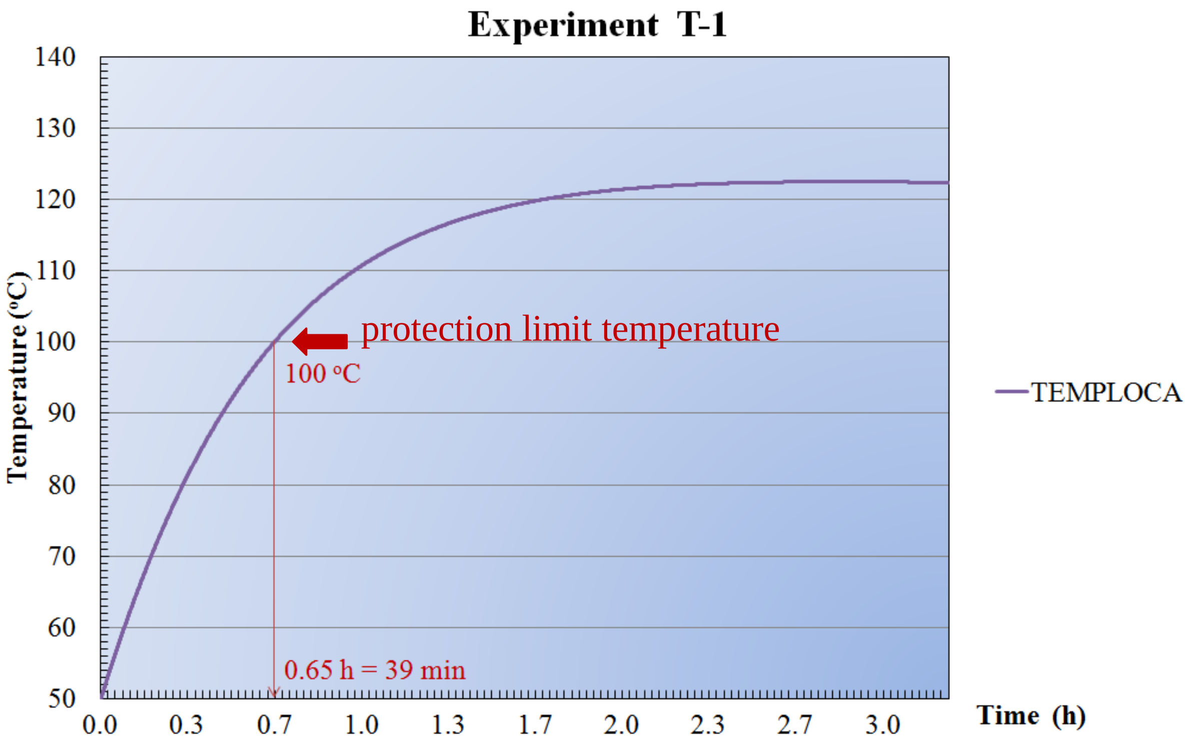

Figure 6: Estimated cladding temperature of IFA – T-1 Experiment.

The T-2 Experiment will be identical to the T-1 Experiment, but with time to the beginning of the experiment of 36 hours after the reactor shutdown. The results of cladding temperatures vs time to the T-2 experiment are showed in Figure 7. In this estimate the *protection limit temperature* (100 ^{o}C) would be reached at 18.5 min, with the closure of the experiment.

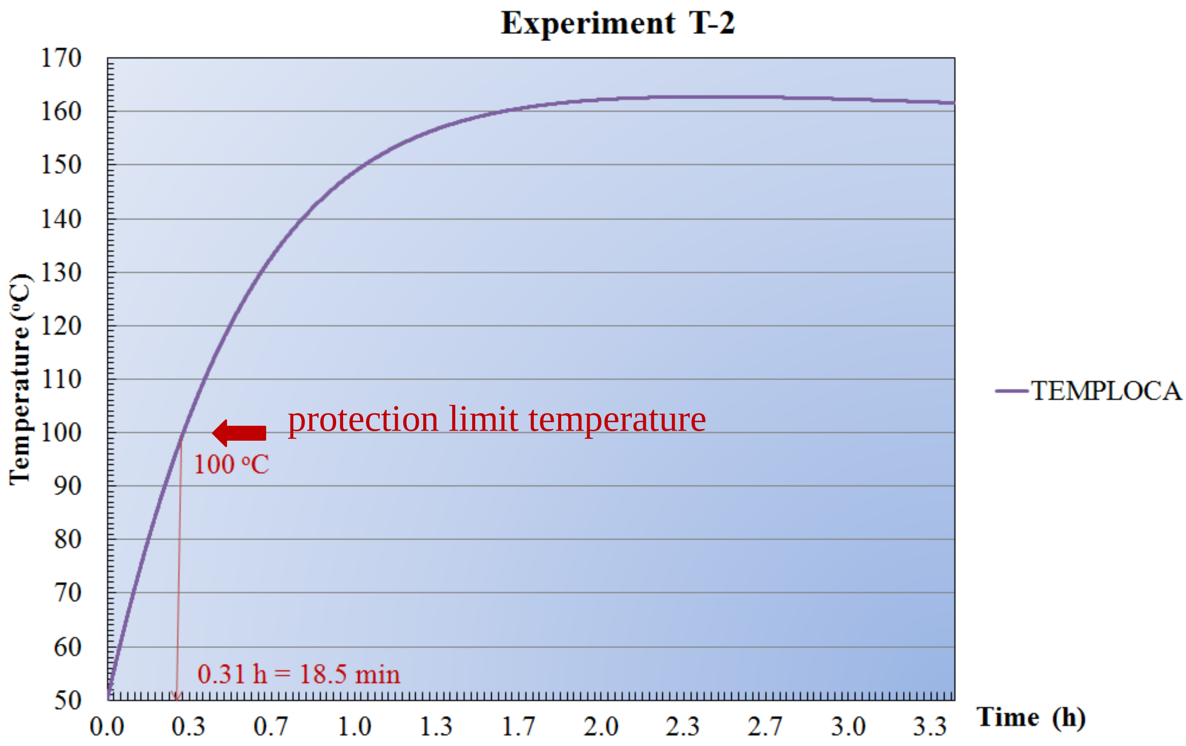

Figure 7: Estimated cladding temperature of IFA – T-2 Experiment.

3.2. P-1 and P-2 Experiments

In the **P–1 Experiment** (P for Partial uncovering), the IFA will be uncovered up to a height below the active length (partial uncovering). In this case, there is an obstruction to natural circulation of the air for cooling the IFA plates. This obstruction is a worst heat removal condition for the IFA and it is very important to be studied. The time to the beginning of the experiment will be 64 hours after the reactor shutdown. The decay heat to P-1 and P-2 experiments was calculated by the equation of Way-Wigner and provided in a table in 3D-AIRLOCA code. Figure 8 presents the results of cladding temperatures vs time to the P-1 experiment.

The **P-2 Experiment** will be identical to the P-1 Experiment, but with time to the beginning of the experiment of 36 hours after the reactor shutdown. Figure 9 shows the results of cladding temperature to the P-2 experiment.

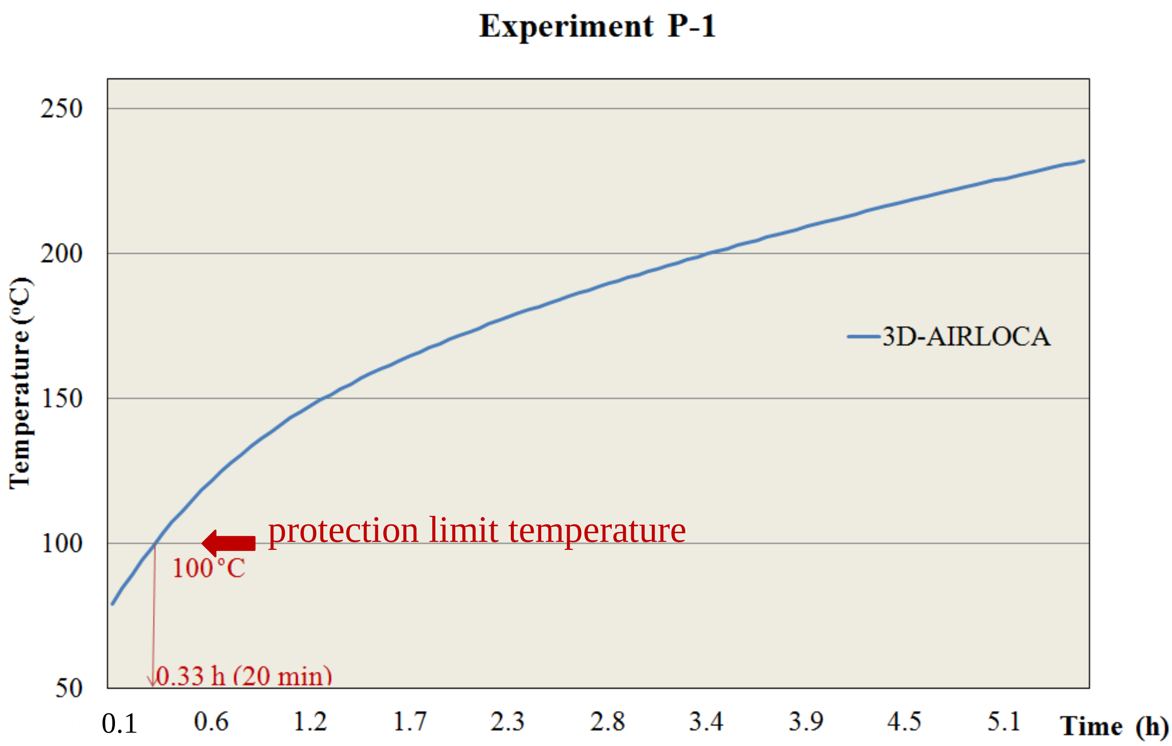

Figure 8: Estimated cladding temperature of IFA – P-1 Experiment.

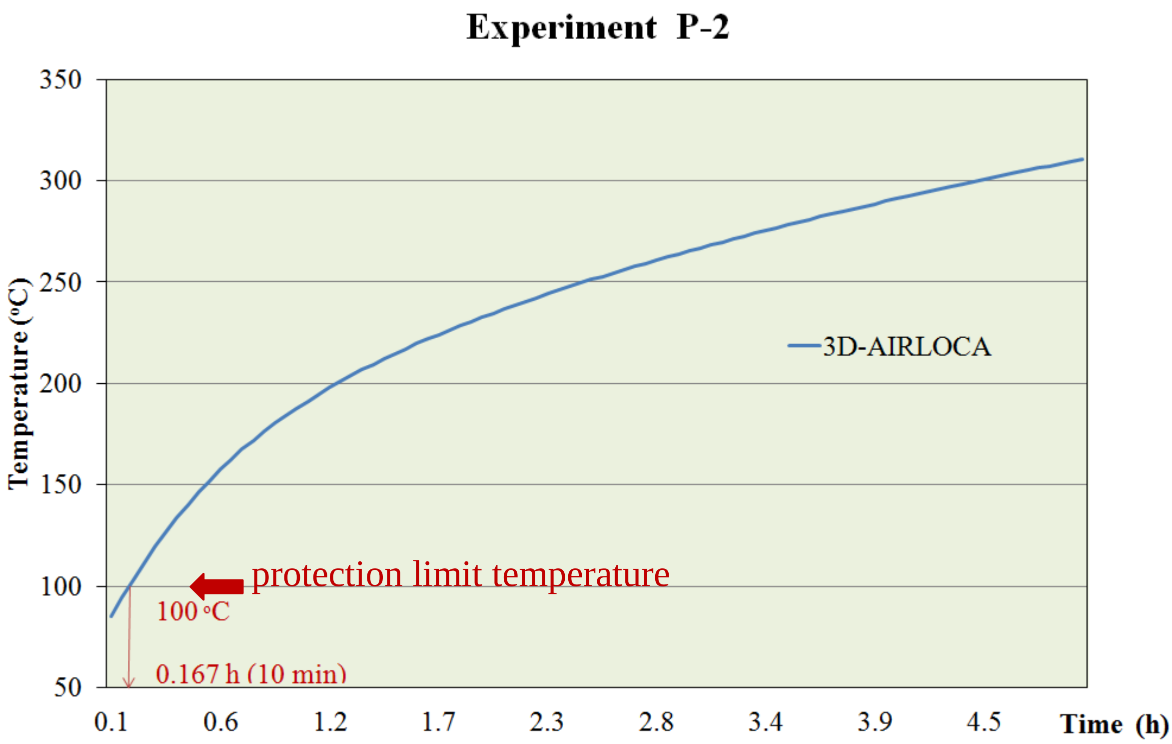

Figure 9: Estimated cladding temperature of IFA – P-2 Experiment.

4. CONCLUSIONS

The STAR section was assembled and installed in the pool of IEA-R1 reactor successfully. The 14 thermocouples of the IFA have proved their efficiency in the DAS successfully [8]. In this test the 14 thermocouples of the IFA were connected to the DAS successfully. The verification of the 4 additional thermocouple (k type) of the section is still pending. The verification of the water level measurement system of the STAR in the DAS has been performed successfully. Tests performed in the compressed air system demonstrated its efficiency, repeatability and control, for emptying and refilling of the section.

The cladding temperature calculations for the 4 experiments (T-1, T-2, P-1 and P-2), with TEMPLOCA and 3D-AIRLOCA programs, allowed an estimate of the time of shutdown for each of them, when the *protection limit temperature* (100 ^{o}C) is reached (39 min; 18.5 min; 20 min; and 10 min respectively).

As next steps are being programmed the conclusion of verification of instrumentation on the DAS, simulation of the experiments of total and partial uncovering of the IFA and the realization of the 4 experiments programmed (T-1, T-2, P-1 and P-2).

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